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SOME ASPECTS OF ELECTRONIC SURVEYING IN OFFSHORE AREAS

by G. A. Roussel

SURVEYING AND MAPPING
DIVISION

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SOME ASPECTS OF ELECTRONIC SURVEYING IN OFFSHORE AREAS

G. A. Roussel[1]

SYNOPSIS

Electronic methods of surveying are finding increasing application for distance measurements and position fixing over water or inaccessible areas, particularly in the control of aerial photography and petroleum exploration operations. This paper describes various electronic methods available with discussions of range, accuracy and operating problems associated with those methods.

Electronic surveying, or radiolocation, as it is also known, is the use of electronic equipment to provide distance or positioning information. A division should be made between radio navigation and radiolocation. The principle differences are the accuracy required and distances at which a position must be determined. For radio navigation a fix within a mile or two will generally suffice and long ranges are required. For radiolocation much greater accuracies are required but the distances involved are generally less than those in radio navigation. Some methods can be used for both radio navigation and radiolocation within limits; but most methods are more suitable for either one or the other.

It is difficult to define exactly the beginning of radiolocation work or electronic surveying, but the greatest developments and expansion in this field have been since 1945. The reason for this is that the electronic techniques necessary to produce the accuracies required for the radiolocation were developed during, and subsequent, to World War II. A large amount of electronic surveying has been done over inacessable, or very rugged land areas, but most of this work is conducted to fix positions or measure distances over water.

Radiolocation has been used to extend geodetic control over long distances; to connect islands to continental areas; and to control hydrographic surveys, aerial photography and aerial magnetometer surveys throughout the world. Most of the work just mentioned has been conducted by or on the behalf of various governmental or military agencies of the countries concerned. Commercially, radiolocation methods have found their greatest use in the field of petroleum exploration and production. At the present time, there are approximately 30 to 35 separate geophysical crews conducting petroleum exploration work in the Gulf of Mexico alone, utilizing electronic control methods. There are probably 5 to 10 other such crews scattered throughout the world. In the petroleum field, electronic surveying is used to control seismographic, gravitimetric, and magnetometric surveys, and to mark positions for the location of drilling operations.

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Radiolocation methods can be classified in two general categories. First there are the circular methods, in which the position is defined by the intersection of two or more circular arcs centered on known fixed points. The second category comprises the hyperbolic methods, in which the position is fixed by the intersection of hyperbolic lines of position. These hyperbolic lines of position are determined by the measurement of time differences or phase differences between radio signals received from pairs of radio transmitters.

In the circular category, the three methods that have found the widest application in offshore work are the radar method, the sonic method, and the Shoran method. Other methods, and modifications of these three methods just mentioned, have been developed from time to time; but, in general, have had limited application.

The radar method, illustrated in figure 1, utilizes a conventional search radar unit installed generally on the vessel whose position is to be determined. The method is based upon measuring the time necessary for a pulse of radio energy to travel to some object, be reflected, and return to the radar equipment. This travel time is converted to a range reading and presented to the operator on a dial or counter on the equipment. The simplest use of this method involves taking ranges and bearings on natural targets or man-made structures which already exist in the area of operation and whose position can be or has been accurately determined. Unfortunately, natural targets or man-made structures very often do not exist in the areas where they are desired for radar control. It is, therefore, necessary in the majority of such surveys to resort to artificial targets to supplement those already existing. These targets may be located on shore or they may be located on a buoy or the mast of a boat which is anchored at a known point in the working area.

The range at which the radar method can be used is from 12 to 25 miles on passive targets such as an oil derrick located on a platform offshore or from 8 to 12 miles on a wire mesh corner reflector located on the mast of a boat, decreasing to 3 to 5 miles if the reflector is located on a buoy. The actual ranges obtained vary with the size of the reflecting object, the transmitting power of the radar equipment, and, because of the high radio frequencies used in radar, the height above the water of the radar antenna and the reflector. The range of the radar method can be increased by the substitution of radar beacons for the corner reflectors. The beacons receive the radar pulses and transmit corresponding pulses in reply. But, as in the case of reflecting objects, the actual range obtained depends upon a number of factors, principally the antenna heights involved and the transmitting power of the radar set and the beacon. The radar method may use two or more ranges for position fixing, or it may use combinations of ranges and bearings. Radar ranges are generally more accurate than radar bearings and are most frequently used, but the bearings serve to identify targets and as a rough check on the position fixed by the ranges.

Some representative figures as to the accuracies obtainable with the radar method as used in the electronic surveying operations along the Gulf Coast are from plus or minus 200 to 300 feet at a range of 2 to 3 miles to plus or minus 500 to 600 feet at a range of 10 to 12 miles. These accuracies are obtainable only by the use of an accurate ranging unit in conjunction with the conventional search radar. In general, radar accuracy decreases as the range increases so that at longer ranges less accuracy may be expected from this method.

The second circular type method which has found considerable application

for offshore surveying is the sonic method, illustrated in figure 2. This method involves buoys which are generally called "sonobuoys." Each buoy contains a hydrophone in conjunction with an amplifier and a radio transmitter, together with an antenna located on top of the buoy. The hydrophone picks up sound vibrations from the water which are amplified and used to trigger the transmitter which sends out a radio signal. In the sonic method, the sonobuoys are positioned in the area of operations. A charge of explosives is detonated to set up a shockwave in the water. This shockwave is received by the hydrophone in the sonobuoy which transmits in return a corresponding radio signal which is received at the vessel. Knowing the velocity of sound in water and the velocity of radiowaves in the atmosphere, it is possible to calculate the distance from the explosion to the buoy once the time is measured between the explosion and the return of the radio signal.

The range of the sonic method as generally used in geophysical work is limited to approximately 6 to 12 miles, depending upon the type of sea bottom, water depth, and size of explosive charge. In some cases where the water is shallow or the bottom very soft the range may be even more severely limited. The accuracy of this method is probably less than the radar method since the velocity with which sound travels through the water is much less constant than the velocity of radiowaves through the atmosphere. It is affected by the temperature of the water and by the salinity of the water. This latter factor may vary considerably in the vicinity of river mouths. Since the sonic method requires the detonation of explosives and is of such short range, this method is readily adaptable only to seismograph operations. It has an advantage for seismograph operations that other methods do not in that the time of detonation of the explosive charge and the time of return of the radio signal from the sonobuoy can be recorded on the seismograph record so that a permanent record can be had of each fix. It is the writer's understanding that the U. S. Coast and Geodetic Survey has used the sonic method with special techniques to measure distances considerably greater than those just quoted. The ranges and accuracies obtained, however, are not known to the writer at present. It is the writer's further understanding that the sonic method is considered obsolete by the U. S. Coast and Geodetic Survey, and has not been used by them since about 1940-41.

The most extensively used and the most accurate of the circular methods is the Shoran method, illustrated in figure 3. This equipment was developed for the Air Force during World War II for aerial photo reconnaissance and blind bombing. It was developed as a short range radio-navigation method but was later found to be admirably suited for radiolocation and surveying. The Shoran equipment consists of the indicating unit located on the vessel and two or more base stations or beacons located at known positions. Although the principles behind the Shoran method are the same as those of a radar set used in conjunction with radar beacons, the Shoran equipment is instrumented quite differently. The indicating equipment can receive signals only from its associated beacons and does not normally pick up echos from reflecting structures in the area. Furthermore, there is no provision in the Shoran method to develop information pertaining to the bearings of the beacons. The Shoran indicating equipment differentiates between the beacons by sending out its transmitted pulses on two separate frequencies shown as F1 and F2 in figure 3. Each base station receives interrogating pulses on its particular frequency, and re-transmits corresponding pulses back to the indicating station on a third radio frequency, F3. Circuits incorporated in the indicating equipment keep the replies returning from the two beacons separated to eliminate confusion.

The two return pulses from the beacons are presented simultaneously to the operator on a cathode ray oscilloscope along with a marker pulse. When the return pulses are properly aligned with the marker pulse, the ranges to the two base stations are read on dials on the front of the equipment.

Having been so designed, the Shoran method is readily adaptable for controlling surveys conducted with aircraft. These have been principally aerial photographic and aerial magnetometer surveys.

Because the Shoran equipment operates on frequencies of from 200 to 325 megacycles, the range obtainable depends principally upon heights of the antennas involved. With 100-foot towers on the base stations located at sea level and 40- to 60-foot antenna heights on the vessel, ranges from 25 to 35 miles can be obtained. The range offshore can be increased by placing the base station equipment on vessels and anchoring them at points offshore which have been surveyed in by the Shoran indicating vessel. Accuracy is sacrificed, however, each time this is done since the base station vessels cannot hold a precise position when anchored. When used with aircraft, the range of the Shoran method may be considerably increased depending upon the height at which the aircraft will fly. The accuracy of the Shoran equipment as generally used in geophysical operations is plus or minus 50 to 75 feet on any one range. An important fact in this connection is that the Shoran accuracy is almost completely independent of the range being measured. This is not the case with most other electronic surveying methods. With very accurate calibration methods and rigid operating procedures, the accuracy of the Shoran equipment can be increased to approximately plus or minus 30 feet plus 2-1/2 feet per 100 miles of range being measured. These modifications and operating procedures are not practical for most commercial operations for economic reasons. These methods have, however, been used by governmental agencies, including military agencies, in this and other countries for long-range triangulation using aircraft. With high flying aircraft and by utilizing these rigid operating and calibrating techniques, it was possible to measure lines of 200 to 400 miles in length with accuracies comparable to those of first-order triangulation.

By combining some of the techniques of Shoran with some of those from Loran, the U. S. Coast and Geodetic Survey developed a longer range survey method for hydrographic surveys. This they call E.P.I., Electronic Position Indicator. By operating at approximately 1,800 kilocycles, they have measured lines from ship to shore up to 500 miles in length. Unfortunately, the techniques necessary to operate this equipment at the lower frequencies have resulted in a somewhat lower order of accuracy than Shoran and more rigid operating requirements. With E.P.I., the U. S. Coast and Geodetic Survey has measured lines from 100 to over 400 miles in length with accuracies from 1:1,300 to 1:7,000. It is believed that the equipment is capable of even greater ranges. Unfortunately, the frequencies necessary for operation of E.P.I. are not available in the United States for commercial operations.

As mentioned previously, the hyperbolic methods define a position as the intersection of two hyperbolic lines of position. These hyperbolic lines of position are determined by measurement of time or phase differences between radio signals from pairs of transmitters. The method known as Loran depends upon the measurement of time differences. It is, however, a long range radionavigation method without sufficient accuracy for surveying purposes. There are three methods presently available for surveying that depend upon the measurement of phase differences between continuous wave radio signals. These are known by the trade names of Raydist, Lorac and Decca.

For the purpose of briefly discussing the hyperbolic method, let us consider figure 4, which diagrams a Raydist network and will serve to illustrate its operation. Points A, B, and C represent radio transmitter locations on shore. If we plot the lines of equal phase difference between stations A and B we will generate a family of hyperbolas, "a" through "e" in figure 4, with transmitters A and B as the foci of the family. Similarly, the lines of zero phase difference between transmitters B and C will give a second family of hyperbolas, "1" through "5," with B and C as the foci. The distances between adjacent lines of zero phase difference is known as a "lane." On the base line the lane width is equal to 1/2 of the wavelength being used. This lane width is approximately 275 feet for the wavelengths used in the Gulf Coast area. The indicating equipment on the vessel receives the signals from the three transmitters and by comparing the phase between the signals from transmitters A and B and between the signals from transmitters B and C is able to determine which of the hyperbolic lanes in each family is being occupied by the vessel. The intersection of these two hyperbolas gives the point of position for the vessel. This is illustrated in figure 4 by the location of the vessel at the intersection of hyperbola "b" in one family and hyperbola "2" in the second family. The equipment on the boat has two indicating devices to indicate the readings in both hyperbolic families simultaneously. The relay station as shown in the diagram is added to the network for technical reasons to eliminate the necessity for synchronizing transmitters A, B, and C.

The Lorac system is based upon the same principles as the Raydist system but it does not employ a separate relay station. Instead, in the Lorac system, the end station transmitters A and C are switched at about 10 cycles per second to act alternately as base transmitters and as relay transmitters.

In the Decca system, transmitters A, B, and C are synchronized by using harmonically related radio frequencies, again eliminating the need for the relay station.

The Raydist phase indicators will indicate to 1/100th of a lane width. On the base line this quantity would be equal to less than 3 feet, but, since the hyperbolas spread out as they progress from the base line, the accuracy of this method decreases as the distance from the base line increases. Further, because of the geometry of the network and the angles at which the hyperbolas intersect, the accuracy of a hyperbolic network is better in the center of the network than it is along the edges. In the Gulf Coast Raydist networks, accuracies of plus or minus 200 to 300 feet are obtainable at ranges up to 125 to 150 miles offshore. At ranges closer inshore the accuracy improves to a maximum of approximately plus or minus 15 to 25 feet in the center of the network. The range of a hyperbolic network will depend upon the radio frequencies used and the power of the base transmitters. On the Gulf Coast, using frequencies between 1,750 and 1,800 kilocycles and transmitting powers of 500 watts, the Raydist networks have been used as far as 150 miles offshore. The range and the accuracy of the Lorac method is comparable to that of Raydist when the two use almost identical frequencies and geometrical configurations of the base stations. The Decca method utilizes wavelengths considerably longer than either Raydist or Lorac and consequently should have somewhat less accuracy. The range obtainable with Decca, however, should be somewhat greater.

The Raydist equipment has an advantage over the other two hyperbolic methods in that it can be instrumented in various ways to give more than 30 variations and combinations of hyperbolic, elliptical, and circular configurations. For specialized applications, one of these variations may give better control and simpler operation than a purely hyperbolic configuration as just described. One of these specialized configurations is quite adaptable to the measurement of a single line, which makes that particular configuration adaptable to measuring long geodetic lines.

The hyperbolic methods have an operational disadvantage in that the equipment on the vessels is capable of indicating accurately the fraction of a lane corresponding to the vessel's position, but it cannot differentiate between lanes. In normal practise, this is overcome by starting at a known point and adding or subtracting lanes, as the case may be, as the vessel moves through the network. If, however, the lane count is lost for any reason, then the vessel must return to a known point to re-establish the proper count. Precautions are taken to guard against this lane loss and in actual practise it does not occur frequently. No practical lane identification feature has been developed yet for either Raydist or Lorac within the presently allotted frequency band. However, Decca is said to have operational lane identification at this time.

As a matter of general interest, Raydist is being used as a means of tracking jet aircraft and guided missiles. It is also used to determine the speed of ships during builders' and acceptance trials. In the latter application one instance of note was the trials of the liner, United States. Decca has not been used in the United States up to the present time. This is due principally to the unavailability of the harmonically related radio frequencies needed for the Decca method. Decca, has, however, been used extensively in other parts of the world, principally for radionavigation, although some hydrographic work and geophysical survey work has also been so controlled.

It was mentioned earlier that most of the commercial electronic surveying done is in connection with overwater geophysical surveys within the petroleum industry. These surveys generally consist of a location grid covering the area of interest. The spacing of the lines of the grid may vary from 1/2 mile to 4 to 6 miles apart, and the spacing of the points to be located along these lines may be from 500 feet to 2 or 3 miles depending upon the type of geophysical operation being conducted.

In general, the coordinates of the desired locations are determined prior to the time that the crew leaves for the working area. Depending upon the electronic surveying method to be used, these coordinates are converted to radar or Shoran ranges or hyperbolic lane readings either by manual plotting or by calculation. These ranges or lane readings are given to the radiolocation operator who then, by use of his electronic equipment, directs the boat to each location in turn, in some predetermined order. The number of positions set in a twelve hour day may vary from 20 to 25 for gravity meter operations to 200 to 300 for seismograph operations. The scale most generally used for the final geophysical maps is 1 inch to 4,000 feet. Other scales used are 1 inch to 2,000 feet, 1 inch to 3,000 feet, 1 inch to 5,000 feet, 1 inch to a mile, and 2 inches to a mile.

For making locations for a drilling platform or other offshore structures, more care is generally taken than is the case with a particular geophysical survey position. The operator of the surveying equipment uses the predetermined ranges or lane readings to guide the vessels to the desired location, taking particular care to occupy the desired coordinates as closely as possible. As the vessel passes the location a small buoy is dropped overboard. In many instances the operator will make several passes dropping a buoy each time so that eventually a cluster of buoys is set. If the structure is not to be built immediately, then a larger, more permanent buoy is set in the center of the cluster. Readings are then made on the permanent buoy and these readings are taken as the final position. When construction is to begin immediately this larger buoy is generally omitted.

In the circular methods, such as Shoran or radar, if more than 2 ranges

are used for control, the position is generally set using that pair of ranges that gives the best angle of control. The other ranges are then read and the final position is adjusted either mathematically or graphically. The various ranges may be given different weights in this adjustment process if there is reason to believe that some ranges are less reliable than others.

Figures 5 and 6 are illustrations of the accuracies obtainable with the Shoran method for offshore locations without resorting to other than normal calibration and operational procedures. These two figures show diagrammatically two well locations that were actually made with the Shoran method and which were later checked with a visual survey, after the drilling structure was built. In figure 5 we have only two Shoran ranges of 8.9 and 26.0 miles intersecting at an angle of 37 degrees. In this instance, the Shoran position was displaced from the transit position by 122 feet. The location shown in Figure 6 was made using ranges from 4 Shoran beacon positions. These 4 ranges from 13.1 to 22.1 miles in length, were adjusted by the method of least squares to give the final Shoran position which differed from the transit position by 43 feet.

Let us now examine some of the problems experiences in commercial electronic surveying operations. Some of these we have mentioned previously, such as the problem of obtaining sufficient range. One of the major factors in any electronic operation is the availability of suitable radio frequencies on which to operate. At the present time, the radio frequency spectrum is extremely crowded. This situation is becoming worse with each year that passes. More and more uses are being found every day for radio equipment with the result that there are no longer sufficient radio frequencies to supply all requests without a large amount of negotiation and sharing of frequencies.

Frequencies necessary for the radar method are available. These are the same frequencies used for radar equipment on board ships and aircraft for normal navigational purposes. Since most radar sets are of narrow antenna beam width, high frequency and relatively low antenna heights, there is little probability of interference between these units. Radio frequencies for the sonic method are also available without too much difficulty. However, the frequencies necessary for the Shoran method, the most useful of the short range circular radio-location methods, are becoming unavailable in the United States quite rapidly. At the present time, the only area in the United States approved for commercial Shoran operation is off the coast of southern California. The frequencies necessary for the operation of the Shoran equipment are normally assigned to our military agencies. These agencies are developing more and more equipment operating in the Shoran frequency band and to which the Shoran equipment may cause distructive interference. For this reason, the military is reluctant to grant permission for commercial Shoran operations except in special cases for limited areas. It is anticipated that even this permission will not be granted much longer.

In connection with the Shoran equipment the question occurs as to why not modify the equipment to operate in another more available frequency band. This has been done in one instance, but the modification, involving a shift to 3000 megacycles region, is quite costly, requires replacement of 75% of the present Shoran equipment with new equipment, and involves a loss of approximately 20% of the present Shoran range. Since relatively short range is already the limitation of the Shoran method, this shift to 3000 megacycles has not been thought generally practical; and it is believed that, eventually, all of the commercial Shoran operations in the United States will be superceeded by one or more of the phase comparison methods. For operations outside of the

jurisdiction of the United States military forces, Shoran continues to be an extremely useful tool for radiolocation operations.

The phase comparison methods of Raydist and Lorac were granted, in the spring of 1952, sharing rights with other users to the 1750 to 1800 kilocycle band. At the present time, there are some 50 radiolocation stations operating within this band along the Gulf Coast from Brownsville, Texas to Key West, Florida. This band has a definite limitation for operations elsewhere, since it can be used only within 150 miles of the Gulf of Mexico. This limitation is placed by the Federal Communications Commission in order to eliminate interference with other users of the same frequencies. At the present time, application is pending before the FCC for use of this band in areas other than the Gulf of Mexico; however, it may be months or years before such use is approved, if at all. The 1750 to 1800 kilocycle band does not allow enough spectrum space for operation of practical lane identification methods in conjunction with Raydist or Lorac. Applications are pending before the FCC for use of the 90 to 110 kilocycle band for lane identification and other purposes; however, there is no assurance as to when or if these applications will be approved. The frequencies necessary for some of the specialized Raydist configurations can sometimes be obtained with considerable difficulty. To date, however, such frequency grants have only been for limited times in certain areas.

The frequencies necessary for the Decca method are unavailable in the United States at the present time. Applications are pending in this connection also for operation in the 70 to 130 kilocycle band, but again, there is no assurance that approval of these applications can ever be granted due to other uses to which that band is being put at the present time. The frequencies necessary for operation of the EPI method used by the Coast Geodetic Survey are available as far as the writer knows only to government agencies.

Another of the problems of the radiolocation methods is that of improving the accuracies of the various methods. In connection with the short range circular methods such as radar or Shoran, this involves principally, improvements in electronic techniques and equipment design. However, in connection with the continuous wave phase comparison methods, there are other problems concerning propagation velocities and distortion which are not merely problems of equipment design. The solution in this case lies with the amassing sufficient data and information of sufficient accuracy to allow some of the vagaries of propagation to be determined for various areas so that they may be predicted and corrections therefor inserted in the method.

Another factor affecting the use of radiolocation methods is the cost of such surveys. These are generally higher than those of conventional transit surveys on land; however, for offshore work of for surveys over inaccessible terrain, the electronic methods are very often cheaper per mile of operation than a transit survey to control the same operation. One of the reasons for this is that visual surveys are of short range and very dependent upon good visibility, whereas the electronic methods are of longer range and generally independent of visibility conditions. For commercial operation in the United States, the cost of a radiolocation crew will vary from $6,000.00 per month to $12,000.00 per month, depending upon the type of survey being conducted, working schedule, area of operations, and other factors. For foreign operations these costs are generally from 25 to 50% higher than for domestic commercial operations. The use of radiolocation methods for high altitude aerial photography, long range geodetic control, or hydrography in remote areas may involve costs many times those just mentioned, because of the special

techniques required, transportation problems, and other factors peculiar to particular operations. There has been considerable discussion in the past as to whether the speed of the electronic methods over conventional surveying methods justify the increased costs. There is a lot to be said on both sides of the question. However, there is no magic formula to be applied and each particular operation must be examined on its own merits for justification of the costs involved.

In addition to the problems just mentioned, there are those of actual construction and operation of the radiolocation methods involved. These are so many and varied that we do not have time to discuss them. Again, each individual method in a specific area will have its own particular problems.

In closing, let us look briefly to the future. Undoubtedly, radiolocation or electronic surveying is still undergoing a developmental period. The lack of range, the inaccuracies of the various methods, and the relatively high costs will undoubtedly all be improved with new techniques. Those of us who have used these electronic methods and followed their developments through the years, are confident that the future will see many improvements in techniques and equipment, and that the use of these methods will increase within the fields of surveying already entered and spread to those wherein electronic methods have not been tried.

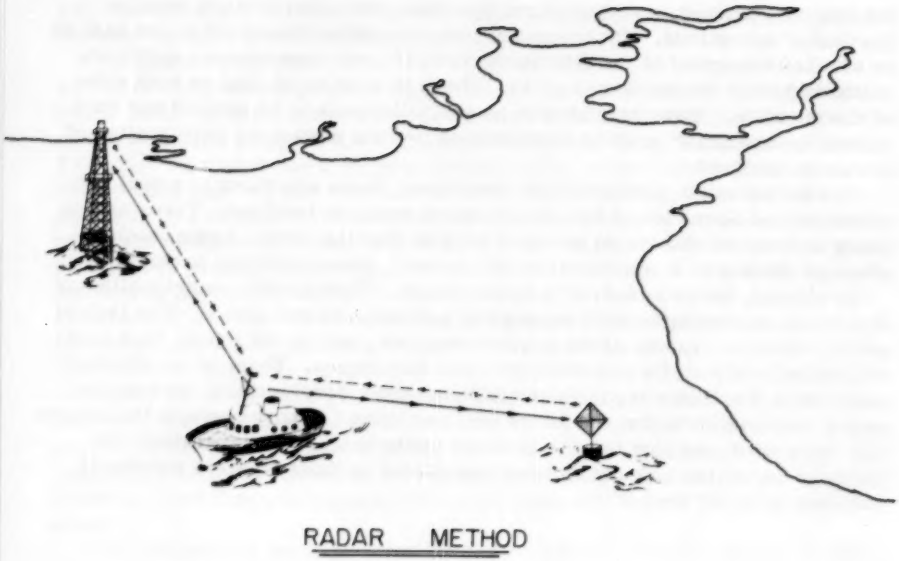


FIGURE 1.

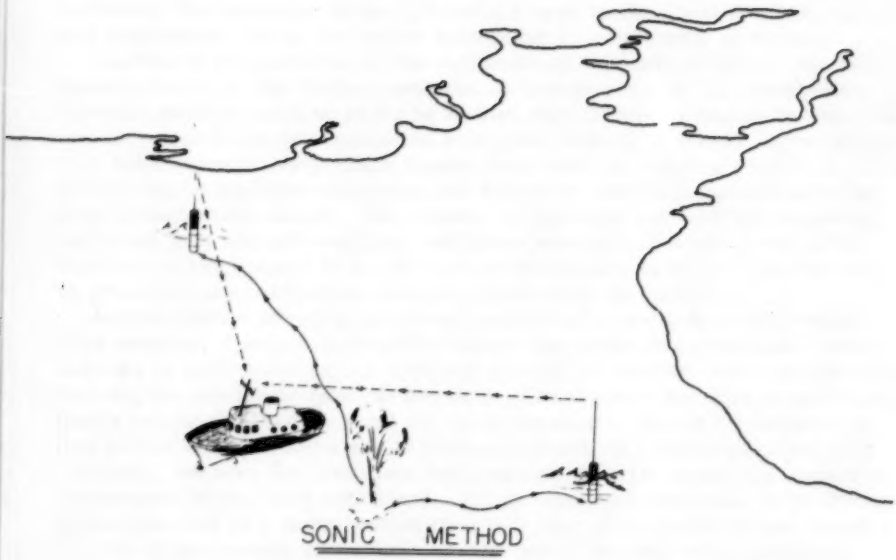
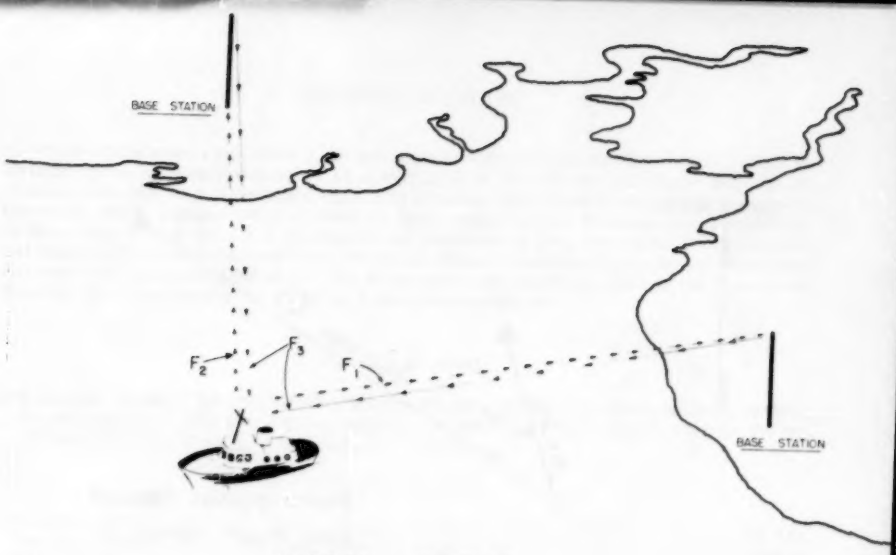
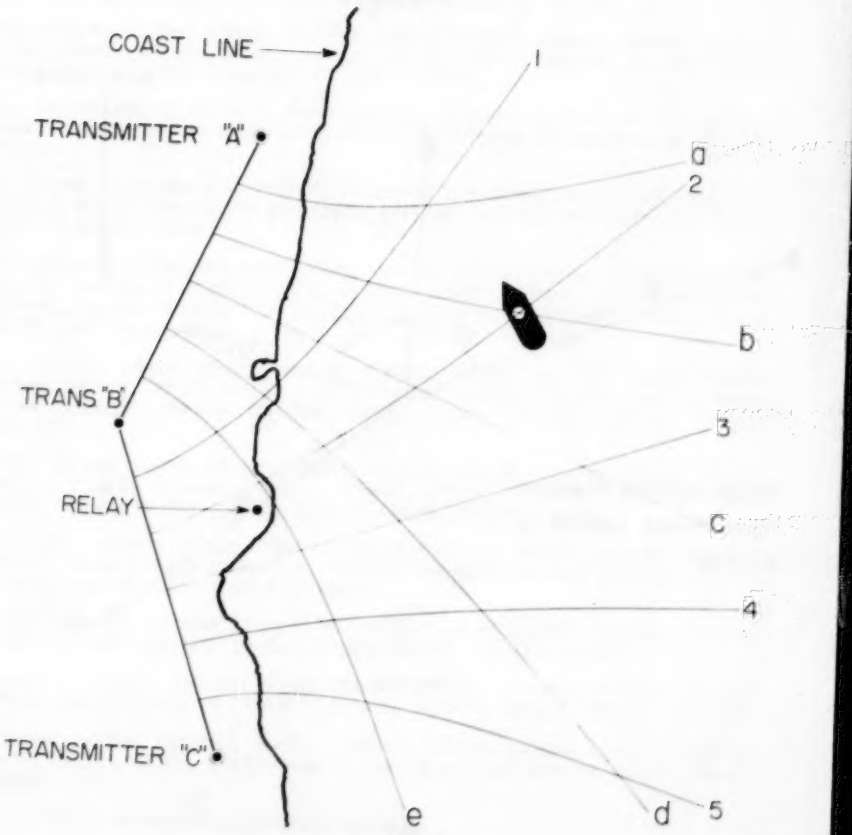


FIGURE 2.



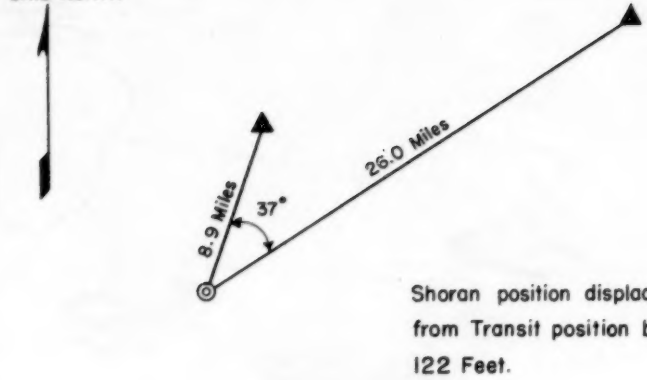
SHORAN METHOD

FIGURE 3.



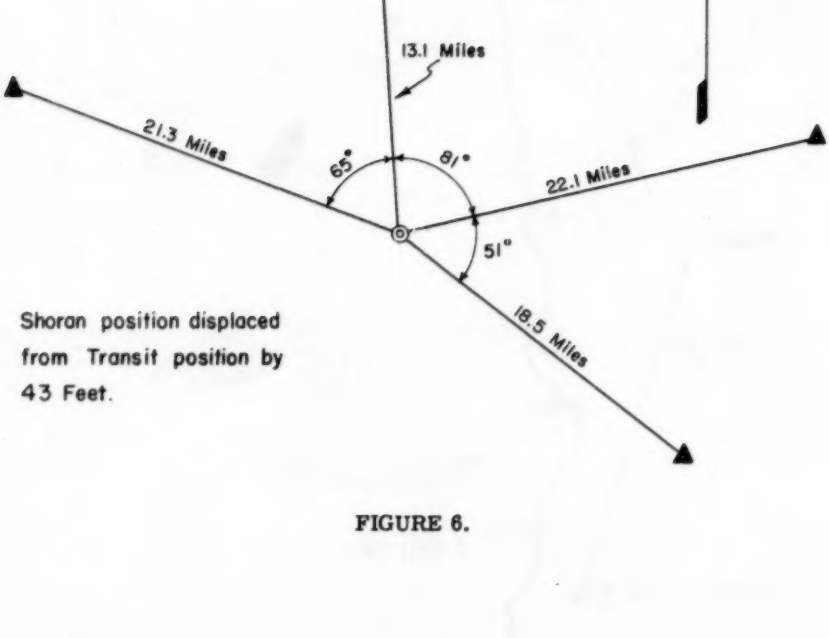
RAYDIST METHOD

FIGURE 4



Shoran position displaced from Transit position by 122 Feet.

FIGURE 5.



Shoran position displaced from Transit position by 43 Feet.

FIGURE 6.

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JANUARY: 583(ST), 584(ST), 585(ST), 586(ST), 587(ST), 588(ST), 589(ST)[c], 590(SA), 591(SA), 592(SA), 593(SA), 594(SA), 595(SA)[c], 596(HW), 597(HW), 598(HW)[c], 599(CP), 600(CP), 601(CP), 602(CP), 603(CP), 604(EM), 605(EM), 606(EM)[c], 607(EM).

FEBRUARY: 608(WW), 609(WW), 610(WW), 611(WW), 612(WW), 613(WW), 614(WW), 615(WW), 616(WW), 617(IR), 618(IR), 619(IR), 620(IR), 621(IR)[c], 622(IR), 623(IR), 624(HY)[c], 625(HY), 626(HY), 627(HY), 628(HY), 629(HY), 630(HY), 631(HY), 632(CO), 633(CO).

MARCH: 634(PO), 635(PO), 636(PO), 637(PO), 638(PO), 639(PO), 640(PO), 641(PO)[c], 642(SA), 643(SA), 644(SA), 645(SA), 646(SA), 647(SA)[c], 648(ST), 649(ST), 650(ST), 651(ST), 652(ST), 653(ST), 654(ST)[c], 655(SA), 656(SM)[c], 657(SM)[c], 658(SM)[c].

APRIL: 659(ST), 660(ST), 661(ST)[c], 662(ST), 663(ST), 664(ST)[c], 665(HY)[c], 666(HY), 667(HY), 668(HY), 669(HY), 670(EM), 671(EM), 672(EM), 673(EM), 674(EM), 675(EM), 676(EM), 677(EM), 678(HY).

MAY: 679(ST), 680(ST), 681(ST), 682(ST)[c], 683(ST), 684(ST), 685(SA), 686(SA), 687(SA), 688(SA), 689(SA)[c], 690(EM), 691(EM), 692(EM), 693(EM), 694(EM), 695(EM), 696(PO), 697(PO), 698(SA), 699(PO)[c], 700(PO), 701(ST)[c].

JUNE: 702(HW), 703(HW), 704(HW)[c], 705(IR), 706(IR), 707(IR), 708(IR), 709(HY)[c], 710(CP), 711(CP), 712(CP), 713(CP)[c], 714(HY), 715(HY), 716(HY), 717(HY), 718(SM)[c], 719(HY)[c], 720(AT), 721(AT), 722(SU), 723(WW), 724(WW), 725(WW), 726(WW)[c], 727(WW), 728(IR), 729(IR), 730(SU)[c], 731(SU).

JULY: 732(ST), 733(ST), 734(ST), 735(ST), 736(ST), 737(PO), 738(PO), 739(PO), 740(PO), 741(PO), 742(PO), 743(HY), 744(HY), 745(HY), 746(HY), 747(HY), 748(HY)[c], 749(SA), 750(SA), 751(SA), 752(SA)[c], 753(SM), 754(SM), 755(SM), 756(SM), 757(SM), 758(CO)[c], 759(SM)[c], 760(WW)[c].

AUGUST: 761(BD), 762(ST), 763(ST), 764(ST), 765(ST)[c], 766(CP), 767(CP), 768(CP), 769(CP), 770(CP), 771(EM), 772(EM), 773(SA), 774(EM), 775(EM), 776(EM)[c], 777(AT), 778(AT), 779(SA), 780(SA), 781(SA), 782(SA)[c], 783(HW), 784(HW), 785(CP), 786(ST).

SEPTEMBER: 787(PO), 788(IR), 789(HY), 790(HY), 791(HY), 792(HY), 793(HY), 794(HY)[c], 795(EM), 796(EM), 797(EM), 798(EM), 799(EM)[c], 800(WW), 801(WW), 802(WW), 803(WW), 804(WW), 805(WW), 806(HY), 807(PO)[c], 808(IR)[c].

OCTOBER: 809(ST), 810(HW)[c], 811(ST), 812(ST)[c], 813(ST)[c], 814(EM), 815(EM), 816(EM), 817(EM), 818(EM), 819(EM)[c], 820(SA), 821(SA), 822(SA)[c], 823(HW), 824(HW).

NOVEMBER: 825(ST), 826(HY), 827(ST), 828(ST), 829(ST), 830(ST), 831(ST)[c], 832(CP), 833(CP), 834(CP), 835(CP)[c], 836(HY), 837(HY), 838(HY), 839(HY), 840(HY), 841(HY)[c].

DECEMBER: 842(SM), 843(SM)[c], 844(SU), 845(SU)[c], 846(SA), 847(SA), 848(SA)[c], 849(ST)[c], 850(ST), 851(ST), 852(ST), 853(ST), 854(CO), 855(CO), 856(CO)[c], 857(SU), 858(BD), 859(BD), 860(BD).

c. Discussion of several papers, grouped by Divisions.

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